ESD-TR-66-205

Quarterly Technical Summary

General Research

15 May 1966

Prepared under Electronic Systems Division Contract AF 19(628)-5167 by

Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Lexington, Massachusetts

ESRL

AD0634819

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Issued 17 June 1966

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INTRODUCTION

This Quarterly Technical Summary covers the period from 1 February through 30 April 1966. It consolidates the reports of Division 2 (Data Systems), Division 3 (Radio Physics), Division 4 (Radar), Division 7 (Engineering), and Division 8 (Solid State) on the General Research Program at Lincoln Laboratory.

CONTENTS

DATA SYSTEMS
DIVISION 2

INTRODUCTION

This section of the report reviews progress during the period 1 February through 30 April 1966 for the General Research Program of Division 2. Separate progress reports on Ballistic Missile Re-entry Systems, Graphics, and Project PRESS describe other work in the Division. All the work of Groups 21 and 22 and some of the work of Groups 23, 25, and 28 is therefore reported separately.

F. C. Frick
Head, Division 2

V. A. Nedzel
Associate Head

DIVISION 2 REPORTS ON GENERAL RESEARCH

15 February through 15 May 1966

PUBLISHED REPORTS

Journal Articles*

JA No.

2662	Content-Addressed Memory Using Magneto- or Electro-Optical Interrogation	D.O. Smith K.J. Harte	IEEE Trans. Electron. Computers EC-15, 123 (1966)
2674	A Formal Semantics for Computer Languages and Its Applications in a Compiler-Compiler	J.A. Feldman	Commun. ACM 9, 3 (1966)
2680	On "Error Bounds for Jittered Sampling"	O.A.Z. Leneman	IEEE Trans. Automat. Control AC-11, 150 (1966)

MS No.

1467	Theory of Large-Angle Ripple in Magnetic Films	K.J. Harte	J. Appl. Phys. 37, 1295 (1966)
1470	Sensitive Pulsed Magneto-resistive Measurement of Magnetic Film H_k	R.C. Johnston	J. Appl. Phys. 37, 1466 (1966)
1472	Measured Relaxation Times for the Uniaxial-Anisotropy Spectrum in Nonmagnetostrictive Permalloy Films	D.O. Smith G.P. Weiss K.J. Harte	J. Appl. Phys. 37, 1464 (1966)
1501	Saturable Shielding — A Technique for Nonlinear Coupling in Magnetic Circuits	R. Berger T.S. Crowther J.I. Raffel	J. Appl. Phys. 37, 1359 (1966)

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UNPUBLISHED REPORTS

Journal Articles

JA No.

| 2577 | Random Sampling of Random Processes: Optimum Linear Interpolation | O.A.Z. Leneman | Accepted by J. Franklin Inst. |

Division 2

JA No.

2702	On Pulse Modulated Control Systems	O.A.Z. Leneman	Accepted by IEEE Trans. Automat. Control
2717	Some Remarks on Spectrums of Modulated Pulse Trains	O.A.Z. Leneman	Accepted by Proc. IEEE
2726	Random Sampling of Random Processes: Mean-Square Comparison of Various Interpolators	O.A.Z. Leneman	Accepted by IEEE Trans. Automat. Control
2751	Trial Spacing in Instrumental Running	J.L. Fozard	Accepted by Psychol. Reports

Meeting Speeches*

MS No.

1468A	Origin of Quadrature Flux in Magnetic Films	K.J. Harte M.S. Cohen G.P. Weiss D.O. Smith	International Colloquium on Magnetic Thin Films, Jena, East Germany, 25-28 April 1966
1518	A Digital System for On-Line Studies of Dynamical Systems	J.B. Lewis T.C. Bartee	Spring Joint Computer Conference, Boston, 26-28 April 1966

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*Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

DIGITAL COMPUTERS
GROUP 23

I. COMPUTER SYSTEMS

A. TX-2 Optical Scanner

A final circuit configuration for starting and DC operation of mercury vapor light sources has been obtained, and work on a chassis is about to begin. Modifications of both hardware and software have been outlined to provide scanning operation in a time-shared environment.

B. Typewriter-Keyboard Consoles

Consoles four and five have been placed on-line and checked out. A new source for custom-made golf-ball elements for Selectric typewriters is being investigated.

C. Micrologic Assemblies

The Calendar Clock has been installed. The new Miscellaneous Input Sequence has been built; its sequence switch has been checked out and an off-line control logic box test has been made. The whole system should be on the air by the end of the first week in May 1966.

A second set of DTL gray-to-binary converter cards was installed in one of the two slave scopes. The control box for the main TX-2 console knob register was modified, and level shifters were incorporated to feed its output into the V-Memory Multiplexer. A card box has been wired and will be installed in the master scope cabinet once the curve generators have been moved to a fixed rack location. Shortly thereafter, a set of knobs should be provided for the charactron console.

D. Displays

New cathode-ray tubes having both P-12 and P-7 phosphors were obtained for the slave displays. Their primary feature is an anti-reflective coating bonded to the front of the cathode-ray tube. This bonded glass coating also acts as a safety shield, eliminating the need for the plastic safety shields previously used and the multiple reflections caused by them. Reaction by users has been very favorable and new tubes have been ordered with these shields. The effect on light-pen operation is no worse than that previously encountered by having the plastic safety shields external to the tubes.

E. Data-Terminal Connections

The logic design for the in-out unit required to interface telephone-line data terminals with TX-2 has been completed. This unit, called the Low Speed Data Channel, will connect up to 63 independent terminals of assorted types to the TX-2. A priority chain and terminal identification logic have been used so that all units can be handled concurrently in a random-demand fashion. This unit will be constructed from standard integrated-circuit logic modules.

Western Union Broadband Switching Service, a data set for 1200-bit-per-second asynchronous operation, and an automatic answering unit are being obtained for the data connection to System Development Corporation in Santa Monica, California.

F. Three-D Wand

A three-dimensional position sensing device has been developed as an aid to experimentation with three-D graphics on the TX-2 computer. The apparatus consists of four ultrasonic transmitters mounted on a scope face, and one stylus-like receiver which is used like a light pen. From the four transmitters, 50-kHz pulses are transmitted in a cyclic sequence, one pulse every 10 msec. The computer receives an interrupt whenever a pulse is sent or received. By reading the real-time clock at appropriate times, the software is able to calculate four pulse transmission times, then three coordinates. The existence of the fourth transmitter makes possible an error check and, therefore, extraneous noise and signal reflections can be discarded. Approximately 1 percent of total computation time is required for position calculations and display update. (Light-pen tracking requires about 5 percent for two-dimensional tracking.)

Currently, the hardware is operative and several versions of test software and display are working satisfactorily. The entire package has been embedded in the time-sharing executive, and we are currently debugging this and adapting it to be useful with the three-D display program.

II. CIRCUIT DEVELOPMENT

A. UHF Switching Transistors

Studies are continuing at Philco with Lincoln Laboratory support and participation in an attempt to determine the basic limitations of current planar transistor technology. Photoresist technology has been refined to the point where devices with 0.05-mil (1.25-micron) stripes have been successfully fabricated. The SX-4 transistor has four emitter and five base stripes of 0.05-mil width. It is essentially a half-scale model of the SX-3 described previously. The best SX-4 has a measured peak f_T of 6.4 GHz at 1.0 volt and 5 ma. Moreover, it has f_T values of 4.5 and 1.5 GHz at 1.0 and 0.2 ma, respectively. The very high frequency performance at low currents means that this device would be extremely useful in large, high-speed arrays where power dissipation per circuit must be kept at a minimum.

B. Arrays

As a vehicle for the study of the problem of high-speed multiple-circuit arrays, a 36-bit three-input parity circuit is being designed for fabrication on a single chip. The system will employ sub-nanosecond gates and multilayer metallization. This will provide a useful introduction to the problem of producing still larger systems on a chip.

C. New TX-2 Packages

A new package for use in TX-2, called S12-D, was designed. It is the fastest circuit yet in a TX-2 package. It consists of four 3-way negative AND gates followed by a 4-way OR gate. Typical characteristics are:

Signal levels	0 to -3 volts
Delay (turn-on, turn-off)	7 nsec
Rise time	3.5 nsec

A new package for use in the Memory Bus Switch control section, called LA-22, was designed. It is basically a SPAT LA-3 with a different gating configuration. Each card has two level amplifiers with one 3-way gate and one 6-way gate per amplifier. Construction of the Memory Bus Switch is nearing completion and bench checkout is in progress. Installation of the switch should begin during the next reporting period.

III. MAGNETIC FILM ENGINEERING

A. Clean Room

A temporary modification has been made to the absolute filter in the duct supplying make-up air to the chemical hood in the dark room of the clean area and it is now operating satisfactorily.

B. Fine-Line Etching

Study of the various steps of the photoetching process indicates that particulate contamination is the principal cause of "shorts" and "opens" in etched fine-line patterns.

The dust problem is being combated by performing all critical work in clean benches or in a clean room, by micro-filtering all process solutions, and by employing a brush-etching technique to prevent dust particles or other solid by-products of the etching operation from interfering with uniform etching.

C. Oblique-Incidence Anisotropy

A new explanation for oblique-incidence anisotropy parallel to the plane of incidence[*] is proposed. It is based on our optical dichroism data which showed that the amount of oblique-incidence anisotropy, whether it be parallel or perpendicular to the plane of incidence, is linearly related to the amount of optical anisotropy (differential absorption constant) by the same constant. A fibre axis in crystals of cubic symmetry, even if it existed, could not produce optical anisotropy. Therefore, the origin of parallel oblique-incidence anisotropy, like perpendicular, must be related to crystallite geometric anisotropy.

D. Large-Capacity-Memory (LCM) Digit Circuits

The digit circuit for the LCM has the following components: (1) digit-sense coupler, which couples the sense amplifier and digit driver to the common digit-sense line; (2) sense amplifier; (3) two synchronous clamps, which eliminate level shift in the sense-amplifier output and act as gates to take account of the polarity reversal of the sense signal between memory half stacks; and (4) a flip-flop, which serves as a strobe, buffer-storage resistor, and digit-pulse polarity switch. Four complete circuits are packaged on a 9×5-inch card that plugs into sockets attached directly to the digit lines. The circuits share a single unipolar digit pulser on the card. A test

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[*] W. Metzdorf and H. Wiehl, Paper 1.4, International Colloquium on Magnetic Thin Films, Jena, East Germany, 25-28 April 1966.

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card used with the partial-prototype stack has operated at a cycle time of less than a microsecond in either a read-write or a read-rewrite mode.

E. LCM Memory Stack

The semiautomatic pulse tester is operating, and the mechanism works well. The re-designed Memory-Stack hardware has been assembled, and construction of diode selection arrays is in progress.

Etching of memory elements is proceeding very satisfactorily. Word lines are being generated by scribing the word pattern in photoresist, photoexposing only the large land areas and then etching. Close control of the resist thickness is achieved by immersing the entire substrate in photoresist and slowly drawing it out. Substrates processed this way have excellent line-edge definition, and from zero to twenty opens. Shorts are readily removed with a hand scribing operation. The process for generating 0.002-inch lines on 0.004-inch centers in $\frac{1}{2}$-oz. copper on fiberglass to produce pressure connectors is to apply photoresist as was done with the word substrates, photoexpose with collimated light directly through a scribed negative, and etch. Use of the scribed negative eliminates errors inherent in the use of photographic copies as exposure plates, and collimated light permits spacing the scribed master away from the photoresist surface, which eliminates scratching of the master. Production of pressure connectors is proceeding with a yield of approximately 50 percent.

F. LCM Testing

The new tester with error detection, printout, and improved indexing mechanism is now operational. Testing thus far has been detailed rather than on a go-no-go basis.

G. Content-Addressed Memory

The manufacture and test of an appreciable number of films is being attempted to provide a good indication of what fraction of the films may be expected to be acceptable, and what operating margins may be required for their use. The test equipment is not yet quite adequate for this task, but it is being modified as quickly as possible.

H. Saturable Shielding

An IBM 7094 computer program has been written for the purpose of predicting the response of shielded thin-film memory structures to DC magnetic fields. The program is capable of calculating the magnetization distribution in up to ten overlapping, magnetostatically coupled films with uniaxial anisotropy and rectangular shape.

IV. SYSTEM PROGRAMMING AND APPLICATIONS

A. VITAL

The VITAL compiler-compiler system is now operational, and documentation is available. The system has been employed to produce a compiler for Junior, the programming language used by Group 25 in its on-line computational experiments.

A control package is presently being implemented that will provide an extensive editing and debugging capability coordinated with translation.

B. Mk 5

A symbolic debugging system was made operational as part of the machine language programming system for the TX-2 time-sharing system, APEX. This programming system is known as Mk 5 among TX-2 users and will be referred to by that name hereafter.

Mk 5 enables a user to write and modify programs in macro-assembly language in much the same way as has been possible in Mk 4, its non-time-sharing predecessor. In addition, there are facilities for manipulating programs in the APEX environment; these include methods for transfer to programs to and from APEX and Mk 4.

The very significant innovation of Mk 5 is its introduction to TX-2 users of the very powerful ability of debugging programs in symbolic rather than in octal form as has heretofore been the practice. Mk 5 publishes all user errors, help calls, and trapping information symbolically by referencing addresses in the directive of the program under test. Trapping is permitted by marking symbolically specified locations via suitable meta-commands. Three types of trapping are allowed:

(1) Trap on marked instructions.

(2) Trap on reference to marked data.

(3) Trap on reference to marked data as deferred (indirect) address.

Any combination of these types may be applied to any combination of program and/or data words. Program and data words are not affected in any way by the trapping mechanisms since meta-bits are used for marking purposes.

Two separate software packages are used to service error alarms and traps. Each package prepares a message concerning the symbolic location which induced the alarm or trap, the type of alarm or trap (printed with suitable mnemonics), and the symbolic location of the associated operand if applicable.

After the error alarm or trap message has been published, a user may inquire about the actual run-time state of his program registers, index registers, etc., by specifying their addresses symbolically. Then he may resume operation of the interrupted program, if this is logically possible.

Plans are under way for the utilization of graphical operations as part of the debugging repertoire.

C. Graphical PATSI

A graphical source language version of the PATSI simulation language has been created. A user can draw a block diagram of a filter-amplifier system and then simulate its operation.

D. Character Display

A program has been written for displaying a new set of characters prepared by Group 25. This set has been drawn with lines and parabolas; circles have not been included. At present, the program displays the old character in the upper left corner of the scope and the new character, larger size, in the center. There will be a facility for changing any character desired by changing the end points and tangent points via the light pen. This part of the program is in progress, but is not completely operational.

COMPUTER COMPONENTS
GROUP 24

I. MAGNETIC FILMS

A. Anisotropy Spectrum of Magnetic Films

In the present method of studying the anisotropy spectrum of magnetic films by means of a hard axis anneal, all anisotropy contributions are excited simultaneously, making subsequent analysis difficult. Therefore, a complementary experiment has been devised in which each contribution is excited separately by means of a rotating field of period τ. Any anisotropy process i with time constant $\tau_i \sim \tau$ will lag behind this annealing field, while all other processes will either follow, be unaffected, or be randomized by the rotating field. Instrumentation to measure the predicted lag of the easy axis is in preparation. Other aspects of the instrumentation as discussed in the last Quarterly Technical Summary[*] are progressing well.

II. OPTICS

A. Magneto-Optics

Birefringent incident and exit media have been introduced into the theory of magneto-optical mode conversion in structures made up of multilayer magnetic and dielectric films. Results are very favorable for either the transmission or reflection conversivity. Conversion efficiencies approaching 100 percent are predicted theoretically and also appear to be physically realizable with presently available materials.

B. Electro-Optics

1. Optical Phase Shifter

Single crystal films of hexagonal CdS have been grown epitaxially on sapphire as a first step in fabricating the optical phase shifter discussed in the last Quarterly Technical Summary.[†]

2. Light Deflector

It does not appear possible to generalize the phase shifter discussed above into an analog light deflector due to boundary conditions not yielding a plane wave solution. Another approach to a deflector is under consideration using propagation along a total internal-reflecting boundary.

III. ELECTRON TRANSPORT

A. Al-Al$_2$O$_3$ Triodes

A high-impedance ($\sim 10^9$ ohms) collecting barrier has been fabricated using biased plasma oxidation. The collection efficiency has been evaluated by means of the internal photoelectron

[*] General Research Quarterly Technical Summary Report, Lincoln Laboratory, M.I.T. (15 February 1966), p. 10, DDC 630918.
[†] Ibid., p. 11.

effect and found to compare favorably with low-impedance ($\sim 10^4$ ohms) barriers. A triode using this high-impedance collector is currently being fabricated.

B. Dry Oxidation Kinetics of Aluminum

Two principal mechanisms have been used in the literature to describe the formation of very thin oxide films on aluminum. The first of these, due to Mott,[1] assumes that electrons tunneling from the metal through the growing oxide film to a suitable trap level provided by the chemisorbed oxygen species produce O^- or O_2^- ions on the oxide surface. As a result of this ion production, an electric field arises in the oxide film which serves to aid the transport of metal cations from the metal through the oxide layer to the oxide surface, where they combine with the oxygen ions to produce more of the oxide. The oxide growth law derived from this mechanism is a pressure-independent inverse logarithmic time law. The second mechanism, due to Lanyon and Trapnell[2] and later adapted by Eley and Wilkinson[3] to the case of aluminum exposed to low oxygen pressures (1 to 10 microns), assumes that oxygen is chemisorbed on the growing oxide film by a process of activated place exchange with underlying metal atoms, thereby producing more of the oxide. The oxide growth law derived from this mechanism is a pressure-dependent direct logarithmic time law. Eley and Wilkinson[3] have observed the direct logarithmic growth law at low oxygen pressures, while Harte[4] has observed the inverse logarithmic growth law at atmospheric pressures. In an effort to resolve the dilemma posed by the observation of two distinct growth laws for the oxidation of aluminum, Eley and Wilkinson[5] suggested that at low oxygen pressures oxide growth takes place by the place exchange process, while at higher pressures (atmospheric) the growth rate by the Mott mechanism exceeds the growth rate due to place exchange, hence the inverse logarithmic growth law is observed.

Our experimental work, involving the simultaneous measurement of oxygen uptake (by weight gain) and contract potential of an aluminum film exposed to dry oxygen at pressures from 1 micron to 10 mm (millimeters), shows the growth law to be a pressure-dependent direct logarithmic law up to the maximum pressure used in the investigation, i.e., 10 mm. No evidence of the pressure-independent Mott potential due to electron tunneling was observed. Instead, the contact potential was found to be logarithmically dependent on pressure in a manner consistent with the production of an electric dipole layer due to chemisorption of neutral oxygen atoms on the oxide surface. In fact, we found that the oxide growth and contact potential kinetics are consistent with the following two-stage reaction

$$\frac{3}{2} O_2 + S_2 \rightarrow S_2O_3 \tag{1}$$

$$S_2O_3 + (Al)_2 \rightarrow Al_2O_3 + S_2 \quad . \tag{2}$$

The first step (1) is an activated chemisorption of oxygen onto the surface S_2 of the growing oxide layer to form a surface-oxygen chemical complex S_2O_3. In the absence of excess aluminum at the oxide surface, the S_2O_3 is stable and causes a change in the contact potential due to the partial ionic character of the surface-oxygen bond. Excess aluminum arriving at the oxide surface from the underlying metal by an activated place exchange process reduces the S_2O_3 to produce more of the metal oxide in accordance with the second reaction (2).

The introduction of small amounts of water vapor into the dry oxygen atmosphere at low pressures (~100 microns) causes the contact potential to stabilize within a few minutes at a value which is relatively independent of pressure and about 2 volts lower than its dry oxygen value for 100 microns of oxygen. At this writing, it is believed that this is the stable Mott contact potential. It is theorized that in the dry oxygen case the acceptor level for chemisorbed oxygen atoms on the growing oxide surfaces lies above the Fermi level of the metal and hence remains vacant. In this case, the oxide can only grow by the place exchange mechanism regardless of the oxygen pressure. The introduction of water vapor results in a chemisorbed layer of water on the growing oxide surface. The polar nature of the water adsorbed on the oxide surface produces a positive-outward, electric dipole layer which lowers the work function (contact potential) of the oxide surface. The acceptor level for oxygen atom chemisorbed on the water-covered oxide surface then lies below the Fermi level of the metal, allowing electrons to tunnel, and oxide growth takes place by the faster Mott mechanism. Experiments are now being planned to test this theory in the near future.

IV. ADVANCED CIRCUITS

A dual sample, hold, and threshold circuit card was designed and built for Group 23 for use in the high density film memory plane tester. The circuit enables rejection of word noise by sampling the signal and the base line at different times and subtracting.

REFERENCES

1. N. F. Mott, Trans. Faraday Soc. 36, 1 (1940).

2. M.A.H. Lanyon and B.M.W. Trapnell, Proc. Roy. Soc. (London) A227, 387 (1955).

3. D.D. Eley and P.R. Wilkinson, Proc. Roy. Soc. (London) A254, 327 (1960).

4. R.K. Harte, Proc. Roy. Soc. (London) A236, 68 (1956).

5. D.D. Eley and P.R. Wilkinson, Structure and Properties of Thin Films (Wiley, New York, 1959), p.508.

PSYCHOLOGY
GROUP 25

I. ON-LINE COMPUTING SERVICES FOR SCIENTISTS AND ENGINEERS

A. APEX

APEX is the executive system that time-shares the TX-2 computer. In part, it was designed to support investigations of the computing services needed by scientists and engineers working on-line.

The past quarter has been primarily a shakedown and debugging period. Although incomplete, the system has been operational throughout the quarter, and time-sharing now accounts for about two-thirds of the TX-2 time devoted to applications (as opposed to equipment changes, etc.). The system currently handles five consoles, three of which have a CRT display in addition to the standard keyboard and typewriter.

The shakedown and debugging activities have restricted the number of new programs that could be added to the system. A new program has been implemented which enables meta-bits to be set and cleared by the executive rather than by the user program. The meta-bits can now be restored after drum swaps, and an efficient debugging facility utilizing meta-bits is available in time-sharing.

Some changes have been made to the user-switching algorithm to improve response for small users under saturation conditions, but more work must be done in that area before the effect of large users on small ones can be held to more acceptable limits.

The most important remaining requirements are routines for the IBM magnetic-tape and for the paper-tape punch. Work continues on these routines, and on the Xerox printer routine, which although usable, is not satisfactory in several respects.

B. The Lincoln Reckoner

The previous report[*] described an initial, experimental facility that was based on the APEX system and was intended for scientists and engineers to use on-line in dealing with the computational problems that arise in their day-to-day work. This facility is now called the Lincoln Reckoner.

The three fundamental components of the facility — the Basic Translator, the Procedure Builder and Runner, and the initial library of public routines — are now stabilized. Of course, it is always possible that new routines will be added and that minor defects will be found in existing routines; however, the user can now feel confident that he will not be inconvenienced by unexpected improvements.

Much of the past quarter has been devoted to disposing of a number of minor details that are often neglected in an effort to finish a new facility. In the present case, these included

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[*] General Research Quarterly Technical Summary Report, Lincoln Laboratory, M.I.T. (15 February 1966), p. 15, DDC 630918.

error messages, documentation, the printing of text, and numerous other details. Furthermore, some initial work has been done on new routines that will display procedures and arrays of data on the CRT.

C. Test of the Reckoner

A small "field test" of the Reckoner facility is under way. About twenty scientists and engineers from the Laboratory have been introduced to the Reckoner and invited to use it to solve substantive numerical problems encountered in their work. Over a period of six weeks, two time-shared consoles will be kept available to these users for four hours a day, four days a week. The purpose of the test is to determine to what extent a facility of this kind meets the needs of scientists and engineers. In particular, it is a test of the idea that the researcher, with or without a computer background, can work on his problem on-line, directly and with an absolute minimum of programming activity. The test will also serve to uncover weaknesses in design which will be revealed by use of the Reckoner on a wider range of problems than those attempted so far.

In part, the test was undertaken with the idea of implementing a similar facility on the IBM 360 that is to be acquired for time-shared use throughout Lincoln Laboratory.

II. HUMAN INFORMATION PROCESSING

In previous experiments, it was found that if a person is given two acoustic stimuli — say, two digits — one presented in the clear and the other masked by wide-band noise, and is asked to say whether they are the same or different, he performs better when the clear stimulus is presented first.

An experiment has been done to investigate how his performance is affected by the time between the two stimuli. The stimuli were digits spoken by the TX-2 computer, and the time interval between the masked digit and the clear digit was varied from $-10\,\text{sec}$ (i.e., the clear digit $10\,\text{sec}$ before the masked) to $+10\,\text{sec}$ (i.e., the clear digit $10\,\text{sec}$ after the masked). The effect of the time interval on the fraction of the decisions made correctly was relatively small. The most striking effect was on the response bias. Over most of the range of time intervals, there was a large bias toward reporting that the two stimuli were different; but when the clear digit was in the neighborhood of $1\,\text{sec}$ after the masked digit, the bias vanished. This seems to imply that with different time intervals the information about the first stimulus is stored or processed in different ways.

III. QUANTITATIVE METHODS

Further work has been done on a procedure that has been called nonlinear-additive analysis. It is a way of analyzing the results of an experiment in which the dependent variable is a function of more than one independent variable. Let x_{ij} be the value of the jth independent variable at the time of the ith observation, and let y_i be the ith observation. Multiple regression, which is the most common procedure, finds the coefficients $\hat{\beta}$ that minimize

$$\sum_i \left(y_i - \sum_j x_{ij}\hat{\beta}_j \right)^2 \quad .$$

The nonlinear additive procedure, which seems to be useful in analyzing certain kinds of judgment data, attempts to find the coefficients $\hat{\beta}$ and $\hat{\gamma}$ that minimize

$$\sum_i \left[y_i - \hat{\gamma}_0 - \hat{\gamma}_1 \left(\sum_j x_{ij} \hat{\beta}_j \right) - \hat{\gamma}_2 \left(\sum_j x_{ij} \hat{\beta}_j \right)^2 - \ldots - \hat{\gamma}_n \left(\sum_j x_{ij} \hat{\beta}_j \right)^n \right]^2 \quad .$$

In practice, a computer program is required. The iterative procedure described earlier[*] has now been supplemented by a practical, approximate rule for choosing n, the degree of the polynomial, and by a better criterion for deciding when the iteration has been carried far enough. Several methods for speeding the convergence of the process have been investigated, but the procedure described earlier still seems to be the most practical compromise between computation time and the complexity of the program.

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* J. L. Morey and D. B. Yntema, Proceedings of the Second Congress on the Information System Sciences, J. Walker and D. Spiegel, editors (Spartan, Washington, 1965).

COMPUTER SYSTEMS
GROUP 28

I. COMPUTATION CENTER DEVELOPMENT

A series of delays in both hardware and software schedules has caused installation of the IBM 360 Model 67 to be postponed until early June 1966. At that time, an interim configuration, without drum or multiplexer channels, will be installed. By late July, the final items will be added to complete the system. Because of this new schedule, the 7094-II will be retained until late summer. The 360 Model 65 will be held only until the Model 67 is in operation.

Checkout of Operating System/360 has progressed to a point where it is now available to the Laboratory for general use. This does not imply a perfectly reliable system, but it does indicate that within certain known restrictions the work of conversion from present IBM 7094 programs may begin. A machine language assembler and COBOL (Common Business Oriented Language) and Fortran compilers are being used. This general release of the system should have the dual effect of uncovering system errors more quickly and of beginning the long sought relief for the heavily taxed 7094-II.

The Lincoln Laboratory built interface with the 360 Model 40 for the operation of CalComp plotters has been checked out. Attention will now be focused on the paper-tape reader punch, thus completing the last peripheral task still limited to the IBM 1401 system. Coaxial cables have already been installed in the computer room to bring telemetry data to the 360 Model 40 or Model 65. This connection will be completed early in May with the delivery of an IBM 2702. At the same time, the first six communication consoles will be added to the system for familiarization and system control.

II. HYBRID COMPUTATIONAL FACILITY

All functional components of the Digital Differential Analyzer (DDA) have now been built and operated. Proper operation of all logic components at the 4-MHz clock rate has been verified and the interconnection of the DDA to the LINC computer is almost complete. Test programs are now being prepared to check the operation of the entire system. The interface between the LINC/DDA combination and the IBM 360 system also has been completed and actual intercommunication can be done at any time.

RADIO PHYSICS
DIVISION 3

INTRODUCTION

This section summarizes the General Research efforts of
Division 3 for the period 1 February through 30 April 1966.
A substantial portion of the Division's activities is devoted
to the PRESS Program, reports for which appear in the
Semiannual Technical Summary Report and the Quarterly
Letter Report to ARPA.

S. H. Dodd
Head, Division 3

M. A. Herlin
Associate Head

DIVISION 3 REPORTS ON GENERAL RESEARCH

15 February through 15 May 1966

PUBLISHED REPORTS

Journal Article*

JA No.

| 2648 | Upper Limit on 2- and 3.75-Centimeter Radiation from Blue Stellar Objects | I.I. Shapiro
S. Weinreb | Astrophys. J. 143, 598 (1966) |

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UNPUBLISHED REPORTS

Journal Article

JA No.

| 2721 | Note on the Effect of Shadowing on the Backscattering of Waves from a Random Rough Surface | R.A. Brockelman
T. Hagfors | Accepted by IEEE Trans. Antennas Propag. |

Meeting Speeches†

MS No.

| 1604 | Incoherent Scattering from the Ionosphere | J.V. Evans | Seminar, M.I.T., 18 March 1966 |
| 1648 | The Polarization Parameters for the 1665-Mc/s OH Emission from W3 | M.L. Meeks
J.A. Ball
J.C. Carter | American Astronomical Society, Hampton, Virginia, 28-31 March 1966 |

SURVEILLANCE TECHNIQUES
GROUP 31

Group 31 maintains and operates the Millstone radar system and the Haystack research facility at the Millstone Hill Field Station. The Group conducts research programs that include the development of satellite observation techniques and studies of the ionosphere and auroras. Significant programs in radar and radio astronomy are in progress at both Haystack and Millstone. The Group also assists the Space Communications Program.

I.   OPERATION, MAINTENANCE, AND IMPROVEMENTS

A.   Millstone Radar

Venus observations were conducted twice weekly during most of this quarter. By early April 1966, because of the increasing distance to the planet, signal strengths were reduced to a point where delay measurement accuracy was not sufficient to be useful, and further observations were suspended. A number of lunar measurements were also carried out during this quarter.

No auroral observations were made. Satellite tracking of Space Defense Center priority objects continued on approximately a one-day-per-week schedule. Millstone continued to act as the prime target illuminator in the MITRE/Millstone interferometer system. Assistance was provided to the Group 82 optical tracker in acquiring and tracking satellites. L-band ionospheric backscatter observations continued on a one-day-per-month basis.

B.   Haystack Research Facility

During this report period, the antenna was utilized 1167 hours; 809 hours were used for operations, and 358 hours for installation and maintenance. Trial periods of 24-hour-per-day operations lasting as long as 10 days were successfully attempted in the radiometric mode.

Three different forms of radar operation were accomplished, all exercising the 100-kw X-band transmitter. CW radar operations were conducted for the planets Venus and Mercury. Pulsed radar operations of the moon used the high-voltage modulator and the TR switch for the first time at power levels of 75-kw peak. New equipment was installed and successfully operated for radar polarization studies.

Tests of the stability and spectral purity of the X-band radar were made by leaking transmitter signals into the receiver and processing them digitally. Results of these tests show that phase coherence can be maintained over periods as long as 20 sec. The consolidation of frequency and timing for the Millstone complex was begun in April with the construction of a small room in the corner of the Haystack control room which will house the ultra-stable oscillators and associated standards for the two sites.

Modifications were made to the azimuth and elevation cable wraps to provide added services for the new 500-kw Planetary Radar System. Preliminary measurements of the thermal distribution and surface irregularities across the reflector were carried out as part of planning

for readjusting the surface for 35-GHz operation. Finally, a new hydraulic servo valve is in final design which should provide smoother angular drive of the antenna at very slow (sidereal) and very fast ($\sim 1°/\text{sec}$) rates.

C. Haystack Planetary Radar Development

Assembly of the new Planetary Radar (PR) Box for Haystack is continuing. Major milestones in the development of the subcontracted items are:

(1) A beam test vehicle* was built and operated to verify the design and performance of the klystron gun and collector assemblies; final assembly of the microwave tubes is now in progress.

(2) The traveling-wave maser was operated successfully but failed to meet all environmental requirements. The deficiency, deriving from the vapor cooling system, is being corrected by immersing the maser structure in liquid helium.

(3) The beam control unit is awaiting final tests at the vendor's plant.

II. SPACE SURVEILLANCE

A. Orbit Upgrading

Except for final documentation, all remaining items in both of the orbit upgrading computer programs called for in the contract with TRW Systems have now been delivered. Integration of these programs into the Millstone radar system is essentially completed. Tests of the real-time program in actual satellite tracking operations will begin early in the next quarter. Full-scale use of both the real-time and non-real-time programs is planned for June 1966.

B. Tracking Support

Data on 83 tracks representing 37 different priority objects were passed to the NORAD Space Defense Center during this quarter. In support of the Lincoln Laboratory Space Communications Program, LES-3 and LCS-1 were tracked several times for cross-section measurement and orbit refinement. Molnia I, the Russian Communications Satellite, was tracked on four occasions but attempts to locate Molnia II, whose orbital elements are poorly defined, were unsuccessful. At the request of NASA, an attempt was made unsuccessfully to track the Imp-I satellite (which had not been seen in many months) on the day of its predicted decay.

III. LUNAR STUDIES

The lunar studies, supported principally by NASA under Contract NSR 22-009-106, are reviewed more fully in separate Quarterly Progress Reports. The first of these, dated 15 February 1966, has been issued and a second report is in preparation. A review paper summarizing all the previous moon radar observations has been written and will be presented at the Ninth Plenary Meeting of COSPAR in Vienna. The work is summarized below.

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* Essentially a klystron without RF interaction components.

A. Millstone Observations

Measurements of the depolarization of incident circularly and incident linearly polarized waves were made during the present quarter. These were reported at the Spring URSI Meeting and form part of a paper which reviews the 23-cm observations and which has been submitted to the Journal of Geophysical Research.

B. Haystack Observations

Incoherent short-pulse radar observations of the moon for two weeks have been made during this report period at 3.8-cm wavelength. Sufficient data were obtained to redetermine the scattering law at this wavelength with a delay resolution comparable to that employed earlier at 68 and 23 cm. In addition, a search was made for a systematic difference in the reflection coefficient for waves polarized in and orthogonal to the local plane of incidence. The effect is known to be present at 23-cm wavelength, and has been interpreted as indicating the presence of a layer of light material overlaying most parts of the surface. The effect was found also at 3.8 cm, but somewhat diminished in amplitude. If the original interpretation is correct, this may mean that there is a continuous gradation of the density of the surface material with depth.

IV. PLANETARY STUDIES

A. Millstone Observations of Venus

Radar observations of Venus were made twice each week from the beginning of the report period until 7 April, when the last detection was obtained. These observations yielded the range delay to Venus with an accuracy of ±0.01 msec until 21 March, at which time it became necessary to employ longer pulses that yielded an accuracy of about ±0.04 msec. No further planetary observations using Millstone are planned for the immediate future.

B. Haystack Observations

1. Venus

Venus has been observed in nine separate all-day experiments, and Mercury has been observed in two experiments during the report period. CW radar observations of Venus have confirmed that the cross section is small (~1.2 percent) at X-band near inferior conjunction. However, as the planet moves away from inferior conjunction, the cross section appears to increase. The increase (about a factor of 2) seems to begin when the terminator reaches or nearly reaches the subradar point. This behavior suggests that the low cross section arises from atmospheric absorption, and that the temperature in the sunlit atmosphere rises, thereby reducing the attenuation.

Experiments to determine the angular scattering law using pulse transmissions failed to yield the complete law. Accordingly, a number of frequency spectra obtained in CW observations have been averaged to obtain the scattering function for the planet at X-band. By comparing this function with that reported by the Jet Propulsion Laboratory group at S-band,[*] we find

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[*] D. O. Muhleman, Radio Science (National Bureau of Standards Journal of Research) 69D, 1630 (1965).

evidence for atmospheric attenuation with a one-way value of 2 db, if it is assumed that the intrinsic reflection properties of the surface are the same at X- and S-bands. Observations of Venus using the Haystack radar are expected to continue at two-week intervals for several months.

2. Mercury

The measurements against Mercury confirmed that the X-band cross section is about 5 percent as observed earlier, and served as a check on the accuracy of the Venus observations.

3. Shapiro Test of General Relativity*

Detailed planning is now complete for carrying out the Shapiro test of general relativity. By using a continuous shift-register, phase-reversal coding of the transmitted CW waveform, it appears possible to process the received echo in such a way as to enable a delay measurement to 10-μsec accuracy by the conclusion of a day's observation of either Venus or Mercury. The first application of this technique is planned during the superior conjunction of Venus in November 1966.

V. ATMOSPHERIC STUDIES

A. Ionosphere

UHF backscatter observations have been carried out for a period of 48 hours each month and L-band observations for 12 hours each month during the report period. The analysis of the 1964 results is nearing completion. Work is under way to perform a greater part of the data analysis by machine computation and should lead to a considerable reduction in the amount of time required to analyze our 1965 results.

B. Aurora

Auroral observations were discontinued in January 1966; however, analysis of the data and preparation of a report on the results are continuing. Contour maps showing the spatial distribution of the auroral echoes and their aspect sensitivity are in preparation.

VI. RADIO ASTRONOMY

A. Radiometric Observations

During the current reporting period, the Radiometer (R) Box was installed on the Haystack antenna 34 days. However, not all radiometric observation was restricted to this time. The cooled parametric amplifiers in the Radar/Communications (R/C) Box were used successfully to observe the hydrogen recombination lines in the frequency range 7791 to 7798 MHz, corresponding to the principal quantum number transition n = 95 to 94. Some difficulties were experienced in attempting these observations; however, at the end of the current period, successful measurements were made on the Orion and Omega Nebulae. These initial measurements show that the scientific usefulness of Haystack can be extended to an important new area of radio astronomy.

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* I. I. Shapiro, "Effects of General Relativity on Interplanetary Time-Delay Measurements," Technical Report 368, Lincoln Laboratory, M.I.T. (18 December 1964), DDC 614232.

The most interesting observations of this period were associated with the quasar 3C273, which was observed at wavelengths of 3.75 and 2 cm. The flux of this source has shown a significant rate of increase with time during the report period. The flux at 3.75 cm is increasing at the rate of 15 percent per year, while at 2 cm the rate is a surprising 80 percent per year, sufficiently high for significant changes in flux to be observable in an interval of two weeks. Other quasars are being observed periodically, and significant changes have also been found in the 2-cm flux from 3C84 and 3C279.

The unexpected nature of the polarized OH emission observed from the vicinity of H II regions in our galaxy has led to a program of observation in which these regions are now being studied over a variety of spectral intervals. The three strongest OH spectral-line sources — W3, W49, and NGC 6334 — have been mapped in continuum at 2-, 3.7-, and 18-cm wavelength, and the 21-cm hydrogen spectrum in the direction of W3 has been measured in both emission and absorption.

The mechanism for OH emission is presently not well understood, and members of Group 31 have been working with theoreticians in Division 8 to formulate a satisfactory physical model.

B. OH-Line Interferometer

Construction of equipment for the OH-line interferometer experiment, which will tie the Haystack and Millstone antennas together as a coherent system at 1665 MHz, is proceeding approximately on schedule. Observations of the brightest OH-emission sources will be made during the summer of 1966 as a joint effort with members of the M.I.T. Research Laboratory of Electronics. The development of a radiometer and a focal-point feed for the Millstone antenna is complete, and the Millstone system has been successfully operated under control from Haystack.

VII. SPACE COMMUNICATIONS

The effect of precipitation in both absorbing and scattering microwave signals is important in the design of communications systems. Point-to-point measurements made on the surface of the earth are of limited utility in the determination of these effects on a space communications or surveillance system. To improve our knowledge of the degradation to be expected in these latter applications, measurements of the X-band thermal radiation from clouds and precipitation have been made using the Haystack radiometers.

Interpretation of these data would be greatly facilitated if high-resolution, three-dimensional weather radar maps could be made concurrently. To this end, it is planned to modify the Millstone radar to provide approximately 1-km range resolution. The real-time data-processing facility will be used both to control the radar antenna and to reduce the data.

RADAR
DIVISION 4

INTRODUCTION

This section summarizes the General Research activities of Division 4 during the period 1 February through 30 April 1966. The major portion of Division 4's activities is devoted to Radar Discrimination Technology, PRESS, BMRS, and Space Communications, which are described in separate reports. The General Research activities in Division 4 are carried out by Group 46, which is engaged in work on Haystack instrumentation, millimeter radar, and microwave component development.

<div align="right">

J. Freedman
Head, Division 4

H. G. Weiss
Associate Head

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DIVISION 4 REPORTS ON GENERAL RESEARCH

15 February through 15 May 1966

PUBLISHED REPORTS

Technical Note

TN No.				DDC and Hayden No.
1966-19	Thermal Cracking of Waveguide Windows	C. E. Muehe	9 February 1966	DDC 628907 H-704

Journal Article*

JA No.			
2484	The Packaged and Mounted Diode as a Microwave Circuit	W. J. Getsinger	IEEE Trans. Microwave Theory Tech. MTT-14, 58 (1966)

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* Reprints available.

MICROWAVE COMPONENTS
GROUP 46

I. INTRODUCTION

Group 46 contributes to the radar program through direct participation in specific projects, and through a program of general research which is closely related to the microwave requirements arising from radar projects. Contributions are made to the General Research Program through the support of Haystack Hill, operation of a high-power microwave laboratory, development of low-noise receiver techniques and receivers for space communications, participation in a millimeter-wavelength program, and studies of very-high-gain antennas and antenna feeds.

II. HAYSTACK MICROWAVE COMPONENTS

A. Planetary Radar Box

The Planetary Radar Box for Haystack is under construction. This box will contain a 500-kW CW X-band transmitter and an X-band maser. The skin of the box has been completed. Equipment racks and associated air conditioners, waveguide supports, and coolant manifolds have been installed. About 30 percent of the wiring between the junction boxes and the receptacles external to the PR Box has been completed. Design has been completed, and construction is either in process or completed on all other items to be included in the PR Box.

1. Transmitter

Microwave transmission-line components for power transmission and monitoring between the two Varian Associates VA-949 AM output klystrons and the multimode feed or dummy loads are nearing completion and will be installed shortly. During this quarter, a change to crystal power monitors from thermistors resulted in considerable simplification of the monitoring and safety interlock devices in the four output-power lines to the feed system. The faster response time of crystal detector-operational amplifier units permits one detector at any coupler to serve the multiple purposes of power measurement, video-envelope viewing, and fast or slow triggering of interlock networks. As a result, the coupler arrangement for the monitoring system has been revised to reduce the number of different units needed, while actually increasing reliability by adding desirable redundancy. With the cooperation of the vendors, these changes in quantity and design have been resolved to produce a minimum of delay in delivery and still effect considerable system simplification. Costs will also be slightly reduced.

A "windotron," consisting of two water-cooled, half-wavelength-thick beryllia windows brazed into WR137 OFHC waveguide, was obtained from Varian Associates. The beryllia windows are similar to the output windows intended for use in the VA-949 AM klystrons. The space between the beryllia windows is evacuated and connected to a VacIon pump. The windotron was placed in a high-power resonant ring and tested at power levels up to 436 kW without damage. No window glow was observed. These results constitute a considerable improvement over those achieved with a similar structure using alumina windows, in which window failure occurred at 150 kW.

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2. Antenna Feed and Circular Polarizer

High-power testing of the horn throat has proved the need for hard soldering the stainless steel flanges to the electroformed throat parts. A new throat section is being fabricated of a design which eliminates a troublesome joint and gasket in the present model and which employs hard solder to attach the flanges. A Technical Report on this device is being prepared.

3. High-Power Circulators

Two circulator bodies, which had previously failed during high-power tests, were returned from Raytheon Company after repair. In order to eliminate hot spots at the gap between the alumina matching and the ferrite sections, the gap width was increased to about $\frac{1}{4}$ inch. The circulators were tested at high power in a resonant ring. Hot spots developed in the ferrite sections at various CW power levels above 30 kW, and eventually resulted in chipping of the ferrite. Typically, upon removal of the loose pieces of ferrite, it was found that the power-handling capability of the circulators was improved. Ultimately, both circulators withstood 175-kW CW. A difference in the power-handling ability was noticed, depending on the direction of the power flow through the ferrite phase-shift sections. One circulator withstood 175 kW with power flow in either direction, while the other developed a hot spot at 140 kW with power flow in one direction.

4. Maser

Development of the maser is nearing completion. Acceptance tests are scheduled for the middle of May 1966. During preliminary tests, the maser exhibited a gain in excess of 40 dB with a 3-dB instantaneous bandwidth of 25 MHz. The gain was found to decrease by 6 dB when the maser and dewar were tilted 45° from the vertical. Measures are being taken to solve this problem.

B. L-Band Radiometric Feeds

All parts for the L-band radiometric feeds have been procured and testing will begin shortly.

III. SOLID-STATE AMPLIFIERS

A. X-Band Parametric Amplifiers

Measurements on the idler circuit of the wide-band, X-band parametric amplifier have yielded results that are in reasonable agreement with values predicted by a computer, but not as close as measured and predicted performance at the signal frequency. The additional deviation is believed to arise from the fact that the low-frequency model used by the computer is less exact at the idler than at the signal frequency. It should be noted that the idler frequency is several times the signal frequency.

The first engineering model of an X-band parametric amplifier, designed for low-noise performance, has been completed. Electrical tests have not yet been made.

B. Diode Packages

The purpose of this work is to reduce the values of the parasitic elements of a standard diode package without a change in the external package dimensions. The Micro Optics Company will soon deliver a number of improved packages of a finalized design, together with manufacturing drawings.

Discussions concerning the manufacture of a new, smaller diode package have been held with Micro Optics. Use of these packages will allow the employment of higher pump and idler frequencies for X-band parametric amplifiers, which, in turn, should result in lower uncooled noise temperatures than those presently achieved.

C. Diode Measurements

Construction has been delayed indefinitely on the improved apparatus for the measurement of varactor diode junction capacitance and resistance. Work will be resumed when additional technical support is available.

A Technical Note has been prepared and will be published soon.*

IV. VHF MODIFICATION TO TRADEX ERROR HORNS

Secondary patterns were taken for the alternative approach to the TRADEX VHF modification described in the previous Quarterly Technical Summary.† This design involves the addition of dipoles to the ridges of the existing UHF error horns. The radiation patterns at VHF had half-power beamwidths between 5° and 5.5°. However, the measured gain of 26.4 dB corresponds to an aperture efficiency of 27 percent. Since the RCA version of the modification (which utilizes slotted cavities) produced comparable gain and its design status was further advanced, work on the dipole approach has been discontinued.

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* F. J. Dominick, "Cooled and Uncooled Varactors for Paramp Applications," Technical Note 1966-27, Lincoln Laboratory, M.I.T. (5 April 1966).

† General Research Quarterly Technical Summary Report, Lincoln Laboratory, M.I.T. (15 February 1966), p. 37, DDC 630918.

ENGINEERING
DIVISION 7

INTRODUCTION

The Engineering Division's efforts in support of the General Research Program during the quarterly period ending 30 April 1966 have been principally concerned with improvements and experiments related to the Haystack antenna and to solid state research. Fabrication and outfitting of the Planetary Radar Box, which is to be used for planetary radar measurements, are well under way. Much work is being done on refinements to the servo control and drive systems which rotate and control the motion of the antenna itself. Finally, high-pressure and special-purpose apparatus for solid state research continues to be developed.

J. F. Hutzenlaub
Head, Division 7

MECHANICAL ENGINEERING
GROUP 71

I. HAYSTACK

A. Planetary Radar Box

1. Structure

Fabrication has been completed on the Planetary Radar (PR) Box itself, including additional framing, outside closeouts, Alply siding, honeycomb floor panels, integral rear equipment racks, and inside connector panels. Removable panels were incorporated in the middle roof area and front floor section to facilitate equipment adjustments.

Fabrication is continuing at the Lexington Field Station Annex 1 on the general-purpose box (GP-1); completion is estimated for late summer 1966.

2. Air Conditioning and Water Cooling

The plumbing required for the five fan-coil units in the PR Box has been installed in the frame area below the honeycomb floor. Each fan-coil unit has a 3-way flow valve which is actuated by a temperature sensor in the equipment to be cooled.

Plumbing for the main water-cooling assembly is being installed and pressure tested in the machine shop assembly area.

3. Microwave Hardware

The majority of the microwave components are in manufacturing, including adapter elbows for the temporary VA-849 tube configuration.

The base ground plane, including safety interlocks, and the shroud cover for the Beam Control Unit are being fabricated. The unistrut supports, waveguide brackets, and tube carriage are being assembled in the PR Box. The RF dummy loads, associated hardware, and supports have been designed and are in process of manufacture. Provisions are being made for low-power testing of the PR Box in June 1966 at the Lexington Field Station Annex 2, which will include main water cooling of the waveguide and klystron tubes, balancing the chilled water cycle, and installation of RF dummy water loads.

The maser for the RF box has been completed at the West Coast facility of Microwave Electronics Corporation. This unit is designed for batch liquid gas operation. A second dewar for the unit is being fabricated locally by Vacuum Barriers Corporation, and delivery is anticipated by the first of June. Modifications have been incorporated which allow the liquid helium transfer tube to be left in the container after the transfer has been made. This is required because of the low head room available in the PR Box. Concurrently, a second maser is being fabricated by the Air Products & Chemicals Corporation for closed cycle refrigerator operation. This second unit is scheduled for operation in August 1966.

The pump tube and associated hardware enclosure have been completed at the Laboratory and the assembly is being used at Microwave Electronics' facility. Cold load dewars for use as a reference in the microwave network have been delivered and are awaiting test by Group 46.

4. Site Modifications

Cooling water, chilled water, and service lines have been modified from the tower base to the azimuth wrap. These lines are being installed through the elevation wrap to the equipment box position on the antenna. Completion is expected by 1 July.

In addition, the inside test dock will have an overhead monorail system for tube handling and modified cooling-water manifolds. Two 7.5-ton chillers will be positioned outside the radome area adjacent to the pump room in a temporary shelter. Water lines are to be run from these chillers to the tower base and test dock to service the PR Box fan-coil units.

Design studies are continuing on tube testing equipment at Test Dock No. 3.

B. Antenna Modification

A 500-pound-capacity hoist was installed on the antenna at a station located at the extreme end of the RF box raceway structure. This hoist will facilitate servicing the RF boxes and will permit lifting of miscellaneous equipment for maintenance and operation of the antenna. The hoist is fully automatic and has been electrically interlocked with the antenna control system.

C. Blockage Reduction

The quadripod support structure for the secondary reflector is presently braced at its one-third points by $\frac{1}{2}$-inch aluminum rods. These rods add approximately $\frac{1}{2}$ of 1 percent to the overall system blockage. A fiberglass rope with parallel strands is now being manufactured by Owens-Corning. This material of a smaller diameter will be electrically transparent at X-band frequencies. At the present time, it appears feasible to replace the aluminum rods with a $\frac{1}{8}$-inch-diameter fiberglass tension member.

The detail design of this bracing system will be completed and a test program will be undertaken to measure creep and thermal behavior in the radome environment during the coming quarter. If this works out as expected, it is planned to install these new braces during the surface rerigging in the fall of 1966.

II. MILLSTONE

An L-band interferometer experiment scheduled for early June 1966 will utilize the radiometer box at Haystack and the 84-foot-diameter Millstone tracker. The radiometer box will be fitted with a dual-polarized focal point feedhorn on an 85-inch-diameter reflector. Design efforts have been concerned with the reflector, feed, and waveguide component supports. Reflector testing at the Antenna Range will precede installation at the Haystack site. Fabrication of the components has begun.

At Millstone, a single horn with waveguide components will be mounted on a permanent platform located at the 84-foot-diameter reflector focal point just above the existing secondary reflector. The secondary assembly will be lowered by means of two worm-gear winches and will

be attached to the main feedhorn housing by three "A" frames. Design efforts during this quarterly period were concerned with the waveguide platform, lifting equipment, attachment frames, and cabling from the platform through the torque tube to the rear equipment shelter.

III. SOLID STATE RESEARCH

A. Tensile Testing of Brittle Materials

Investigation of the pinch-off effects on closure units in high-pressure equipment, as well as optimum stress limits in pressure vessels, was conducted. Small rods of various dimensions were compressed in the lateral direction until fracture occurred. By utilizing the strain theory, the fracture load could be accurately predicted for every rod diameter. The results obtained were consistent; therefore, this method can be adopted to determine the tensile strength of brittle materials.

B. 300-Ton Press

The design of a compact self-contained mobile laboratory press has been completed and the unit is currently being fabricated. The press has a load capacity of 300 tons at 6300 psi with a 15-inch-cube working space.

C. Fluoride Furnace

An apparatus has been designed for the fluorination of hydroxyl and oxygen-contaminated fluoride compounds. This purification process will yield oxide-free fluoride laser material, and can operate at temperatures up to 2000 °C.

D. Ellipse-Hyperbola Mirror

Design of an optical system mirror for Group 82 has been completed and fabrication will start during this quarter. This system incorporates an ellipsoidal and a hyperboloidal mirror. The target is mounted at a focus of the ellipsoid, enabling maximum light to collect through a 40° opening at the end of the unit.

IV. LASER RADAR

During the past quarter, the preliminary evaluation of the Nike-Ajax pedestal at Millstone utilizing the telescope originally designed for the Apollo Program and a laser from Applied Energy, Inc., indicated that the system would be satisfactory.

The telescope fabricated by Diffraction Limited, Inc., has been received and is being readied for installation. The diode dewar has also been received from the Janis Manufacturing Company. A dewar support which will allow for vertical and horizontal movement with reference to the telescope is being fabricated, and delivery is expected early in May 1966. A mounting for the light chopping wheel and associated equipment have been designed, and completion of fabrication is anticipated soon.

V. STRUCTURES RESEARCH

Work has continued on the analysis of paraboloidal shells and the structural stability of radomes.

A. Paraboloidal Shell Analysis

Chapter V of the LLAPS (Lincoln Laboratory Analysis of Paraboloidal Shells) User's Manual has been completed in draft form. This chapter deals with the use of the asymptotic integration programs developed earlier and published in Group Report 71G-1, Part IV.[*] Effort is continuing toward completing the reports on previous work.

B. Radome Stability

The formulation of governing equations and refinements in the analytical approach have been made. Further use has been made of existing structures computer programs in this work, and plans have been initiated to modify them to perform a complete buckling analysis without writing completely new programs.

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[*] J. W. Mar and F. Y. M. Wan, "Distortions and Stresses of Paraboloidal Surface Structures — Part IV," Group Report 71G-1, Lincoln Laboratory, M.I.T. (29 April 1964), DDC 600125, H-579.

CONTROL SYSTEMS
GROUP 76

I. HAYSTACK

Effort in this quarter was concerned with the antenna drive, control system development, and reflector rerigging.

A. Hydrostatic Bearing

The bearing pad flow gauges have been received and a mock-up of their installation has been made. All parts are now ready for actual installation during the next quarter.

B. Servo Control

1. Servo Valve

Qualitative flow tests have been performed on the main spool. Depending on its position, flow reaction forces were noted on the spool in the direction of valve null and toward valve full open. The spool will be instrumented to obtain values of force vs travel in order to establish matching requirements with the pilot stage current vs force characteristics.

2. Servo Prototype Electronics

This electronics equipment is to be used to close the full-scale simulated antenna system loop on the hydraulic test stand and to serve as the prototype for the antenna control electronics.

Electronics for control of the servo valve has been developed and "dummy" bench tested. A unique demodulator circuit was developed in the course of this work.

Electronics has also been developed and bench static pressure tested which will provide direct and differentiated motor pressure signals for closed-loop system stabilization purposes.

3. Inertia Rig

Fabrication of the inertia stand is approximately 50 percent complete. Drive take-off assemblies for the tachometer and angle data unit have been completed. The stand is expected to be fully assembled by the end of the next quarter.

C. Hydraulic Test Stand

Continued problems with calibrating flow meters and maintaining constant test conditions have required the design of a closed-loop temperature control system. The necessary control components are on order. A dual temperature control will be provided consisting of pump inlet cooling and a high-pressure pump outlet reheater. Constructed on-site, the reheater will be a special electrical low-watt-per-square-inch unit of our own design.

D. Main Control Console

Wiring has continued on this unit and is 95 percent complete. Pre-installation electrical tests will occur in the next quarter before the console is installed in the control room.

E. Antenna Rerigging

Contracts have been awarded to North American Aviation, Inc., to provide access to both the front and back surfaces of the antenna. Modifications to the optics box will also be made in preparation for a rerigging program scheduled for late this year. Temperature studies are now under way. Encouraging progress has been made in the development of a film-reading system.

SOLID STATE
DIVISION 8

INTRODUCTION

This section summarizes the work of Division 8 from
1 February through 30 April 1966. A more detailed
presentation is covered by the Solid State Research
Report for the same period.

A. L. McWhorter
Head, Division 8

P. E. Tannenwald
Associate Head

DIVISION 8 REPORTS ON GENERAL RESEARCH

15 February through 15 May 1966

PUBLISHED REPORTS

Journal Articles[*]

JA No.

2570	Space–Time Symmetry of Transport Coefficients	W. H. Kleiner	Phys. Rev. $\underline{142}$, 318 (1966)
2591	Properties of InAs Lasers	I. Melngailis R. H. Rediker	J. Appl. Phys. $\underline{37}$, 899 (1966)
2605	Electrical Properties of Metal Oxides Characterized by "Hopping" Charge Carriers	J. M. Honig	J. Chem. Educ. $\underline{43}$, 76 (1966)
2613A	Automatic Potentiometric EDTA and Redox Titrations for Determinations of Stoichiometry	M. C. Gardels J. C. Cornwell	Anal. Chem. $\underline{38}$, 774 (1966)
2621	Superconductivity in the Transition Metal Carbides: $Mo_{4.8}Si_3C_{0.6}$, $Mo_{0.95}Hf_{0.05}C_{0.75}$ and Mo_2C	V. Sadagopan[†] H. C. Gatos	J. Phys. Chem. Solids $\underline{27}$, 235 (1966)
2625	Cyclotron Resonance of Piezoelectric Polarons	D. M. Larsen	Phys. Rev. $\underline{142}$, 428 (1966)
2640	Discussion of "Theory of Nonequilibrium Thermodynamics with Application to the Transport Processes in Solids" by M. R. El-Saden	J. M. Honig	Trans. ASME, J. Heat Transfer, Series C, 62 (1966)
2661	Observation of Interband Transitions in Cd_3As_2	E. D. Haidemenakis[†] J. G. Mavroides M. S. Dresselhaus D. F. Kolesar	Solid State Commun. $\underline{4}$, 65 (1966)
2667	Four–Probe Device for Accurate Measurement of the Temperature Dependence of Electrical Resistivity on Small, Irregularly Shaped Single Crystals	R. W. Germann D. B. Rogers	Rev. Sci. Instr. $\underline{37}$. 273 (1966)
2668	On the Polaron Energy Spectrum	D. M. Larsen	Phys. Rev. $\underline{144}$, 697 (1966)

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[*] Reprints available.

[†] Author not at Lincoln Laboratory.

JA No.

2670	Remarks on "An Explanation of the High Cation Vacancy Concentration and p-Type Conductivity in Semiconductors Containing a Multivalent Metal in Its Lowest Valence State"	R. F. Brebrick	J. Phys. Chem. Solids 27, 617 (1966)
2672	Pseudobinary InSb-InTe System	A. J. Strauss M. D. Banus M. C. Finn	J. Electrochem. Soc. 113, 458 (1966)
2731	Comparative Data on CdS Transducers from $14\,Mc/s$ to $70\,Gc/s$	R. Weber	Proc. IEEE (Correspondence) 54, 333 (1966)
2757	Electron-Beam Pumped Lasers of CdSe and CdS	C. E. Hurwitz	Appl. Phys. Letters 8, 121 (1966)
2760	Polaron Induced Anomalies in the Interband Magnetoabsorption of InSb	E. J. Johnson D. M. Larsen	Phys. Rev. Letters 16, 655 (1966)
2766	Spontaneous and Coherent Photoluminescence in $Cd_xHg_{1-x}Te$	I. Melngailis A. J. Strauss	Appl. Phys. Letters 8, 179 (1966)
2771	Quantum Oscillations in the Ultrasonic Attenuation and Magnetic Susceptibility of InBi	Y. Shapira[*] S. J. Williamson[*] S. Fischler	Phys. Rev. 144, 715 (1966)

MS No.

1459	Ferromagnetism in $CdCr_2Se_4$ and $CdCr_2S_4$	N. Menyuk K. Dwight R. J. Arnott A. Wold[*]	J. Appl. Phys. 37, 1387 (1966)
1463	Reduced Manganese Moment in Manganese Chromite	K. Dwight N. Menyuk J. Feinleib A. Wold[*]	J. Appl. Phys. 37, 962 (1966)
1464	Single-Crystal Growth and Properties of the Perovskites $LaVO_3$ and YVO_3	D. B. Rogers A. Ferretti D. H. Ridgley R. J. Arnott J. B. Goodenough	J. Appl. Phys. 37, 1431 (1966)
1474	Temperature Variation of the Spin-Wave Dispersion Relation	R. Weber P. E. Tannenwald	J. Appl. Phys. 37, 1058 (1966)

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[*] Author not at Lincoln Laboratory.

MS No.

1475	Covalency Criterion for Localized vs Collective Electrons in Oxides with the Perovskite Structure	J. B. Goodenough	J. Appl. Phys. <u>37</u>, 1415 (1966)
1477	Crystallographic Study of Chromium Spinels	P. M. Raccah R. J. Bouchard[*] A. Wold[*]	J. Appl. Phys. <u>37</u>, 1436 (1966)

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UNPUBLISHED REPORTS

Journal Articles

JA No.

2719	Partial Pressures of $Te_2(g)$ in Equilibrium with $Ge_{\frac{1}{2}-\delta}Te_{\frac{1}{2}+\delta}(c)$ from Optical Density Data	R. F. Brebrick	Accepted by J. Phys. Chem. Solids
2727	Photoelectron Statistics Produced by a Laser Operating Below and Above the Threshold of Oscillation	C. Freed H. A. Haus[*]	Accepted by IEEE J. Quant. Electron.
2739	Oscillatory Faraday Rotation of the Indirect Transition in Germanium at 1.7°K	J. Halpern	Accepted by J. Phys. Chem. Solids
2740	Phonon Generation, Propagation and Attenuation at 70 Gc	J. B. Thaxter P. E. Tannenwald	Accepted by IEEE Trans. Sonics and Ultrasonics
2747	Space-Time Symmetry Restrictions on Transport Coefficients. II. Two Theories Compared	W. H. Kleiner	Accepted by Phys. Rev.
2749	Absorption Near the Fundamental Edge	E. J. Johnson	Accepted as chapter in Vol. 3, <u>Physics of III-V Compounds</u>, R. K. Willardson and A. C. Beer, eds. (Academic Press, New York)
2762	An Electron-Bombardment Technique for the Deposition of CdS Film Transducers	R. Weber	Accepted by Rev. Sci. Instr.
2776	Efficient Visible Lasers of CdS_xSe_{1-x} by Electron Beam Excitation	C. E. Hurwitz	Accepted by Appl. Phys. Letters
2802	Observation of the Interaction of Plasmons with LO Phonons in GaAs	A. Mooradian G. B. Wright	Accepted by Phys. Rev. Letters

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* Author not at Lincoln Laboratory.

Division 8

MS No.

1246A	Effects of Strain on Infrared Absorption Spectra of Sulfur-Doped Silicon	W. E. Krag W. H. Kleiner H. J. Zeiger S. Fischler	
1517B	On Ground Hartree-Fock States	T. A. Kaplan W. H. Kleiner	
1557	Oscillatory Magnetoabsorption of the Direct Transition in the Layer Compound GaSe at 1.5°K	J. Halpern	
1564	Homogeneity Range and Thermodynamic Properties of GeTe(c)	R. F. Brebrick	
1566	Electrical Properties and Disorder Model of GeTe	A. J. Strauss R. F. Brebrick	
1575	Optical Properties of the Metal ReO$_3$ from 0.1-12 eV	J. Feinleib W. J. Scouler A. Ferretti	
1576	Interband Magnetoreflection in HgTe	R. N. Brown[†] S. H. Groves	American Physical Society, Durham, North Carolina, 28-31 March 1966
1578	Magnetoplasma Cyclotron Resonance in PbSe	S. Bermon	
1579	Quantum Theory of Kinetic Equations for Electrons in Random Impurities	E. S. Kirkpatrick[†] P. N. Argyres	
1580	Magnetoacoustic Effects at 9 Gc in n-InSb	K. W. Nill A. L. McWhorter	
1581	Mass Anisotropy and Nonlocal Field Corrections to Helicon Propagation in n-PbTe	J. N. Walpole A. L. McWhorter	
1585	Lineshape Analysis of the Magnetoreflection Experiment	M. S. Dresselhaus G. F. Dresselhaus J. G. Mavroides P. R. Schroeder[†]	
1590	Band Structure and Electronic Properties of Europium Metal	A. J. Freeman[†] J. O. Dimmock	
1629	Narrow-Band Electrons in Transition-Metal Oxides	J. B. Goodenough	

[*] Titles of Meeting Speeches are listed for information only. No copies are available for distribution.
[†] Author not at Lincoln Laboratory.

MS No.

1246B	The Effects of Strain on Infrared Absorption Spectra of Sulfur-Doped Silicon	W. E. Krag	Seminar, Purdue University, 22 April 1966
1331A	Semiconductor-to-Metal Transition in Transition Metal Oxides	J. Feinleib	Seminar, Tufts University, 13 April 1966
1492C	The Gunn Effect	A. L. McWhorter	Colloquium, Case Institute of Technology, 28 April 1966
1493	High Pressure Synthesis of Arsenopyrite-Type Ternary Compounds	M. D. Banus M. C. Lavine	AIME Annual Meeting, New York, 27 February – 3 March 1966
1534A	Refractive-Index Changes in Absorbing Media by a Pulsed Laser Beam	P. R. Longaker M. M. Litvak	Seminar, United Aircraft Research Laboratories, East Hartford, Connecticut, 28 April 1966
1545C	Light Beam Self-Focusing in Nonlinear Media	P. L. Kelley	Colloquium, Northwestern University, 11 April 1966
1554	Spectroscopic Studies of Laser-Produced Hydrogen Plasma	M. M. Litvak D. F. Edwards*	
1558	Possibility of Self-Focusing Due to Nonlinear Anomalous Dispersion	A. Javan* P. L. Kelley	Fourth International Quantum Electronics Conference, Phoenix, Arizona, 12-14 April 1966
1561	Electron Beam Pumped Lasers of CdS and CdSe	C. E. Hurwitz	
1567	Photoelectron Statistics Produced by a Laser Operating Below and Above the Threshold of Oscillation	C. Freed H. A. Haus*	
1594	Temperature Dependence of Incoherent Second Harmonic Light Scattering in Liquids	D. L. Weinberg	American Physical Society, Washington, D. C., 25-28 April 1966
1661	The Fourier Expansion for Electronic Energy Bands	G. F. Dresselhaus	
1605	Theory of Excitons	J. O. Dimmock	Colloquium, Colorado State University, 18 February 1966
1617	Research in Narrow Band-Gap Lasers and the Optical and Electron-Beam Stimulation of Semiconductor Lasers	R. H. Rediker	Seminar, Stevens Institute of Technology, 11 May 1966

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MS No.

1627A	Semiconductor Lasers	R. H. Rediker	Industrial Liaison Symposia, M. I. T., 28 April 1966
1645	Laser Radars	R. J. Keyes	
1631	Microwave Amplification and Gunn Oscillations in GaAs	A. L. McWhorter	Seminar, Texas Instruments, Inc., Dallas, Texas, 3 March 1966
1634	Microwave Amplification and Gunn Oscillation in Polar Semiconductors	A. G. Foyt	North American Aviation Colloquium, Thousand Oaks, California, 18 March 1966
1665	Maser Amplification of Inter-stellar OH Emission	M. M. Litvak A. L. McWhorter M. L. Meeks[*] H. J. Zeiger	URSI Spring Meeting, Washington, D. C., 19 April 1966
1673	Computer Installation Management — Small, Medium and Large	V. J. Mason	SDS Spring Conference, Boston, Massachusetts, 30 April 1966

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[*] Division 3.

SOLID STATE
DIVISION 8

I. SOLID STATE DEVICE RESEARCH

Electron beam excitation of mixed crystals of CdS_xSe_{1-x} has produced laser oscillations at several wavelengths in the visible part of the spectrum from 0.69 to 0.49 µ, with up to 20 W of peak output power and as high as 11-percent power efficiency at 4.2°K. The samples were made from high-purity, single-crystal, vapor-grown platelets of seven different compositions varying from pure CdSe to pure CdS. Laser emission always occurred at a wavelength within 10 Å of the peak of the 30- to 50-Å wide dominant spontaneous I_1 line. In all cases, both the spontaneous and stimulated radiation were strongly polarized with $E \perp c$. In CdSe, for 50-keV electrons, a minimum threshold beam current of 50 mA/cm^2, a maximum peak output power of 16 W, and a power efficiency of 8 percent were obtained. These values are typical also for the various mixed crystals studied. For pure CdS, however, the minimum threshold beam current was 1000 mA/cm^2 and the efficiency was only 0.7 percent. This anomalously high threshold and low efficiency were observed in all CdS samples from several different crystals, and as yet remain unexplained.

We observed spontaneous emission at wavelengths from 3 to 15 µ, and laser emission at 3.8 and 4.1 µ from $Cd_xHg_{1-x}Te$ crystals at 12°K excited optically by the radiation from a GaAs diode laser. The sample surface irradiated by the GaAs laser beam was a (110) plane, and two parallel cleaved faces perpendicular to this plane formed the Fabry-Perot cavity. Current pulses of a few microseconds duration were applied to the GaAs diode. The onset of coherent emission occurred at a GaAs diode current of about 1 A, which corresponds to approximately 0.3 W of 0.84-µ radiation. An equivalent threshold current of about 50 mA is estimated if it is assumed that one electron-hole pair is produced by each photon which is absorbed by the sample.

We report also the successful pumping of InSb and CdSe lasers at liquid helium temperature using a pulsed xenon flashlamp. Peak flashlamp power densities in the wavelength interval of 0.6 to 0.2 µ of 15 kW cm^{-2} are obtainable with an f/1.5 one-to-one imaging system. For InSb, we observed minimum threshold power densities of about 700 W cm^{-2} with a 500-µ cavity. Well-defined thresholds of about 4 kW cm^{-2} for a 500-µ cavity were observed in CdSe.

Power output, efficiency, and spatial distribution of coherent emission from PbS and PbSe diode lasers have been measured at about 7°K. A peak power of 24 mW at 2 A with 2-µsec current pulses was measured for PbS. This corresponds to an external quantum efficiency of about 4 percent. The CW power output at 0.6 A was 2 mW. For PbSe, a peak power of 3 mW at 2 A (2-µsec pulses), corresponding to an external quantum efficiency of 1 percent, and a CW power output of 0.2 mW at 0.8 A were measured.

Epitaxial layers of high-purity GaAs have been prepared using an open-tube vapor transport system in a two-zone furnace with Ga placed in the high-temperature zone and the GaAs seeds inserted into the lower temperature deposition region. Pure H_2 from a palladium-alloy diffuser is bubbled through $AsCl_3$ and the resultant gas mixture is passed through the reaction tube. Hall mobilities as high as 70,000 cm^2/V-sec have been obtained in samples with free carrier concentrations of 7.3×10^{14} cm^{-3} at 77°K.

A model for GaAs transferred-electron microwave amplifiers has been developed using a three-slope piecewise-linear approximation for the drift velocity vs electric field curve. Good quantitative agreement is obtained with the DC I-V characteristics and with the admittance and gain data over the frequency range 2.5 to 5 GHz for devices in the 50-μ length range.

II. OPTICAL TECHNIQUES AND DEVICES

Photon statistics of a laser near threshold have been measured, taking into account spontaneous emission noise and residual modulation. The experimental data are in excellent agreement with the theoretical predictions of Glauber.

In the 10-μ spectral region, Cu-doped Ge has been used as a background-limited detector. By the proper choice of high-purity starting material and dopant concentration, the noise equivalent power of typical detectors has been reduced to 2.5×10^{-14} W for a 3- by 3-mm device, cooled to liquid helium temperature. The marked improvement in sensitivity is a result of the increased carrier lifetime obtained in the crystal preparation.

Argon laser discharge anomalies have been studied further using electron densities obtained from Stark linewidths of neutral transitions. The anomalous variation of the discharge and light emission with pressure and magnetic field has now been explained using a theoretical model which takes into account a transition of ion motion from free-fall to ambipolar diffusion at increased electron gas pressures.

A carbon-dioxide laser has been operated as a sealed-off system yielding a power output of 10 W at an efficiency of 7 percent. The output beam is a single TEM_{00} mode operating on a single emission line. Tube lifetime is on the order of 4 to 8 hours, degrading to 50-percent power output for extended periods of operation.

A high-power pulsed ruby laser has been used to range on retroreflector-equipped satellites at ranges up to 1000 nm. The laser and associated receiver were pointed at the targets, using a slave-tracking interconnection with the Millstone radar.

III. MATERIALS RESEARCH

A method has been developed for growing large single crystals of iodine by sublimation in a closed ampule. The ampule, which is tapered to a narrow tip at the upper end, is immersed in a water bath heated to ~75°C. As the water level slowly falls because of evaporation, a single crystal is nucleated at the narrow tip, which is the first part of the ampule to emerge from the water.

The partial pressures of $Te_2(g)$ in equilibrium with Ge-Te samples containing between 1 and 52 atomic-percent Te have been determined by measuring the optical density of the vapor as a function of the temperature of the condensed phases. Results show that, in contrast to SnTe, at sufficiently high temperatures the homogeneity range for GeTe(c) includes compositions of less than 50 atomic-percent Te.

A new phase transformation in InSb has been identified by superconductivity measurements on samples first annealed at high pressures and temperatures and then quenched to low temperature before releasing the pressure. For pressures of 37 and 52 kbar, the phase transformation occurs at 308° ± 7°C and 287° ± 12°C, respectively. Below the transformation temperature,

the high-pressure phase is tetragonal lnSb(ll), with superconducting transition temperature of about 2.1°K. For the high-temperature phase, whose structure has not yet been determined, the superconducting transition temperature is 4.0° to 4.1°K.

The phase diagram of the pseudo-binary lnSb-lnTe system at 37 kbar has been investigated by x-ray and superconductivity measurements on samples annealed at 500°C and quenched to room temperature before releasing the pressure. At 37 kbar, there are single-phase regions with rocksalt structure which extend from 60 to at least 80 mole-percent lnTe, and from pure InTe to at least 90 mole-percent lnTe. The data so far available do not establish whether these two regions are separated by a miscibility gap, or whether there is complete solid solubility between 60 and 100 mole-percent InTe.

The x-ray structure factor for MgO and the atomic form factors of magnesium and oxygen in MgO have been determined by computer analysis of x-ray diffraction data for MgO powders at ten temperatures between room temperature and 500°C. The results for oxygen are generally in good agreement with the theoretical form factor given by Tokonami, although there is some discrepancy between theory and experiment at low diffraction angles.

The threshold energy for laser oscillation in a ruby rod fabricated from a vapor-grown crystal containing 0.01 % Cr_2O_3 was found to be 25J at approximately 90°K. Under the same conditions, the laser threshold for a Czochralski-grown rod containing 0.05 % Cr_2O_3 was 28J. The fact that the thresholds are approximately the same, in spite of the difference in Cr^{+3} concentration, indicates that the crystal quality of the vapor-grown material is quite high.

New or improved analytical techniques have been developed for determining the major constituents in several ternary systems. These include a more accurate method for analyzing rare earth cobalt oxides by complexometric titrations, x-ray fluorescence methods for lanthanum cobalt oxide and iron-nickel-copper thin films, and microprobe analysis of $CdSe_xS_{1-x}$ alloys.

IV. PHYSICS OF SOLIDS

The reflectivity measurements in ReO_3 have now been extended beyond 12 eV, out to 22 eV. In this new range, the reflectivity peaks up to 15 percent at about 14 eV, then slowly drops down to about 9 percent at 22 eV.

The experimental investigation of the band structure of GaSe is continuing. Using spectrographic techniques for higher resolution, the excitonic magnetoabsorption spectrum is now being studied.

The large polaron effects in the interband magnetoabsorption of lnSb, which were predicted theoretically, have now been observed. These results constitute the first direct and unambiguous observation of polaron self-energy effects. Corroborative evidence for the polaron has also been obtained from the observed anomalies in the intraband magnetoabsorption near the longitudinal optical phonon frequency.

The application of a magnetic field to the piezo-optical technique results in a marked improvement in the sensitivity of magneto-optical measurements. The power of this technique has been demonstrated in preliminary results in Ge and lnSb at room temperature.

A detailed analysis of the oscillatory optical reflectivity associated with interband transitions between Landau levels has been carried out. This theory accounts for the differences between the lineshapes observed in bismuth and graphite.

The microwave cyclotron resonance measurements in PbSe have now been extended to n-type material. The conduction band parameters have been determined by matching the experimental results to classical skin effect theory.

The effect of both mass anisotropy and nonlocal field corrections on microwave helicon propagation in n-PbTe has been investigated experimentally and theoretically. As a result of the ellipsoidal band structure, large nonlocal field corrections (including a form of Landau damping) are found even for propagation along the magnetic field.

The propagation of 9-GHz longitudinal ultrasonic waves has been studied in n-InSb at temperatures between 4.2° and 36°K and in magnetic fields up to 25 kG for several crystal orientations and electron concentrations, with particular emphasis on the electronic contribution to the attenuation and velocity of the ultrasonic wave. These experiments have yielded a direct determination of the piezoelectric constant e_{14} and the conduction band deformation potential for InSb, the values being $0.06 \, C/m^2$ and $-4.5 \, eV$, respectively.

It is known from experiment that the magnetic field dependence of the frequency of luminescence from a semiconductor depends on the concentration of free carriers. A variational treatment has been carried out which invokes Thomas-Fermi screening to explain this free carrier effect.

The Fourier expansion technique has now been used to study the energy bands of crystals with diamond crystalline symmetry. A specific application of the method to silicon yields a band model which is consistent with all experimental data.

The calculation for the classical ground spin state of a magnetic spinel with nonmagnetic ions on the A-sites is continuing. Stable spin configurations in a section of the next-nearest-neighbor exchange-parameter space have been determined. The resulting prediction for the spinel ordering in $ZnCr_2Se_4$ does not agree with experiment, and the calculation is being extended in order to obtain the observed configuration.

The magnetic resonance linewidth, measured in the paramagnetic region, of the insulating spinels $CdCr_2S_4$ and $CdCr_2Se_4$ has been compared with a theoretical expression based only on dipolar spin-spin interactions, and relatively good agreement is found. The slightly higher theoretical values may result from the neglect of the next-nearest-neighbor interactions.

Extraordinary simplifications occur over the quantum calculation when calculating the high-temperature expansions of the susceptibility χ and specific heat C with the classical Heisenberg model. This classical model is useful in these cases, since χ and C are extremely insensitive to the spin value.

The work on symmetry of transport coefficients is continuing. A simple method is indicated for obtaining the space-time symmetry restrictions on the field-dependent transport coefficients. Results are given for the thermo-galvanomagnetic coefficients.

Using a principle due to Frenkel for studying collective excitations of complex systems, results such as the "S-wave coupling" on the spin excitation spectrum of superconductors have been rederived. This technique is now being used to study electrical conduction in narrow bands.

The work on nonlinear optics is continuing. Stimulated Raman emission associated with the vibrational mode at $911 \, cm^{-1}$ has been observed in several calcium tungstate single crystals – both pure and Nd^{3+}-doped, at room temperature. Near 20°K, the pure calcium tungstate crystal emits stimulated Raman emission at $911 \, cm^{-1}$, but the Nd-doped crystal emits at $83 \, cm^{-1}$.

Measurements of second harmonic incoherent scattering have now been extended to the region above room temperature. The rapid decrease of the scattering to a plateau, with increasing temperatures, probably arises from the dissociation of molecular clusters.

The reported anomalously intense, polarized, and narrow-band microwave emission of interstellar OH is believed to be due to maser amplification of spontaneous emission. A model has been proposed for obtaining the necessary inverted population by means of near-ultraviolet pumping. A propagation analysis in the presence of a small galactic field indicates that a single, dominant, highly polarized elliptical or circular mode will grow in a given direction.

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (*Corporate author*)	2a. REPORT SECURITY CLASSIFICATION
Lincoln Laboratory, M.I.T.	Unclassified
	2b. GROUP None

3. REPORT TITLE

General Research Quarterly Technical Summary Report

4. DESCRIPTIVE NOTES (*Type of report and inclusive dates*)

Quarterly Technical Summary for 1 February through 30 April 1966

5. AUTHOR(S) (*Last name, first name, initial*)

Frick, Frederick C.   Dodd, Stephen H.   Freedman, Jerome   Hutzenlaub, John F.
Nedzel, V. Alexander   Herlin, Melvin A.   Weiss, Herbert G.   McWhorter, Alan L.
                                                                     Tannenwald, Peter E.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
15 May 1966	64	14

8a. CONTRACT OR GRANT NO. AF 19(628)-5167	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. 649L	General Research QTS for 15 May 1966
c.	9b. OTHER REPORT NO(S) (*Any other numbers that may be assigned this report*)
d.	ESD-TR-66-205

10. AVAILABILITY/LIMITATION NOTICES

Distribution of this document is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
None	Air Force Systems Command, USAF

13. ABSTRACT

This Quarterly Technical Summary covers the period from 1 February through 30 April 1966. It consolidates the reports of Division 2 (Data Systems), Division 3 (Radio Physics), Division 4 (Radar), Division 7 (Engineering), and Division 8 (Solid State) on the General Research Program at Lincoln Laboratory.

14. KEY WORDS

data systems	control research	microwave equipment
digital computers	radio physics	mechanical and structural
computer components	space surveillance	engineering
psychology	radar	solid state physics